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Clash of the Built and Natural Environments: A Vulnerability Index to Flood Risk in Galveston County, Texas

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Clash of the Built and Natural Environments: A Vulnerability Index to Flood Risk in Galveston County, Texas

By

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Report

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Dedication

I dedicate this to my family who has always encouraged me to be the very best version of myself.

Acknowledgements

I would like to recognize Dr. Samuel Brody and Russell Blessing from Texas A&M Galveston for their support in the creation of this research and vulnerability index. This research project was fruitful due to their data, input, and expertise.

Abstract

Clash of the Built and Natural Environments: A Vulnerability Index to Flood Risk in Galveston County, Texas

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The University of Texas at Austin, 2013

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Vulnerability occurs at the intersection of natural geophysical forces and human settlement decisions. When humans decide to place themselves and their homes in harm's way and disinvest in mitigation measures, vulnerability ensues. Human decisions have and continue to play a large role in furthering vulnerability, especially in coastal communities. With roughly 50 percent of the United States' population currently located on the coast and with rapid development only projected to continue, coastal communities will be faced with a future of exacerbated flood events that will result in increased surface runoff, flooding, and economic losses. This report focuses on better understanding how the build environment exacerbates coastal vulnerability. This research involves the creation of a spatial vulnerability index to flood risk for Galveston County which uncovers the degree with which the built environment is exposed to flood risk and how this vulnerability can be responded to in a manner that builds coastal resiliency.

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Chapter I: Introduction

ABSTRACT

Vulnerability occurs at the intersection of natural geophysical forces and human settlement decisions. When humans decide to place themselves and their homes in harm's way and disinvest in mitigation measures, vulnerability ensues. Human decisions have and continue to play a large role in furthering vulnerability, especially in coastal communities. While coasts are beautiful and awe-inspiring, there is no doubt that they are hazard-stricken locations. Today in the United States, roughly 50 percent of the population is located on the coast; this rapid coastal urbanization has materialized into sprawling development patterns that result in an inefficient use of land as well as the loss of natural features that are designed to weather flooding and severe storm events within coastal areas.[1] As rapid development continues and impervious coverage increases, coastal counties will face a future of exacerbated flood events that will result in increased surface runoff, flooding, and economic losses. The intensity and placement of coastal development places even more responsibility on planners and emergency managers to protect communities and the infrastructure they rely on most. This research uncovers the degree with which the built environment in Galveston County, Texas is exposed to flood risk and how the exposure to flooding can and should be responded to by local governments and emergency managers.

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[1] (Beatley 2009)

INTRODUCTION

Flooding remains the most destructive natural hazard in the United States. Floods continue to pose the greatest threat to property, safety and economic well-being of communities in the United States. Despite the slew of federal policies that focus on the implementation of structural and nonstructural mitigation measures, the loss of property and human life as a result of flood events continues to rise across the country.[2] Low-lying coastal areas are met with an intensified flood risk due to population growth, sprawling development patterns and the drastic alteration of natural hydrologic systems through increasing percentages of impervious coverage. The sustained threat of flooding across the nation, especially in coastal communities is not a coincidence. According to Mileti (1999), disasters, such as those produced by flooding events, are the product of human-constructed events.[3] The destruction of disasters is in large part the result of how we build and design human communities with respect to natural hazards.[4] Brody (2011) argues that the rising impact of floods is not solely a consequence of increasing mean annual precipitation, population growth, or inflationary monetary systems; the rising cost of floods is also driven by our development decisions and the wide-ranging impacts that those have on our physical landscape.[5]

Texas has the second largest population in the US living in vulnerable, low-lying coastal areas. Five of the top 20 most populated counties in Texas, including Harris,

[2] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)
[3] (Mileti 1999)
[4] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)
[5] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

Cameron, Brazoria, Galveston, and Jefferson Counties, are located on the coast.[6] Texas coastal counties are inherently vulnerable to flood disasters as population continues to grow within low-lying areas that receive substantial amounts of rainfall. The most recent glimpse of coastal vulnerability for Texas coastal communities occurred when Hurricane Ike made landfall on September 13, 2008. Hurricane Ike is the costliest and most damaging storm to hit the Texas coast since the 1900 Hurricane. With 103 deaths and damages totaling to $24.9 billion, Hurricane Ike ranks as the third most costly storm in US history (without considering damages resulting from Hurricane Sandy).[7]

RESEARCH QUESTIONS

With an inescapable vulnerability to flood risk along the Texas coast, this research seeks to investigate how the placement of the built environment exacerbates this vulnerability for coastal communities. My primary research question asks:

1) How our development patterns accentuate vulnerability to flood risk in the coastal county of Galveston County?

This research seeks to map several geophysical and development elements that contribute to flood vulnerability. My secondary research question asks:

2) Where the critical infrastructure elements of the built environment are located with respect to flood vulnerability in Galveston County?

Determining the vulnerability of critical infrastructure to flood risk will uncover the degree with which communities are vulnerable to severe storm and flooding events.

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[6] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

[7] (Bedient 2012)

This research concludes with suggestions for coastal communities within Galveston County to limit their vulnerability to flood risk and build resiliency through land use and mitigation strategies.

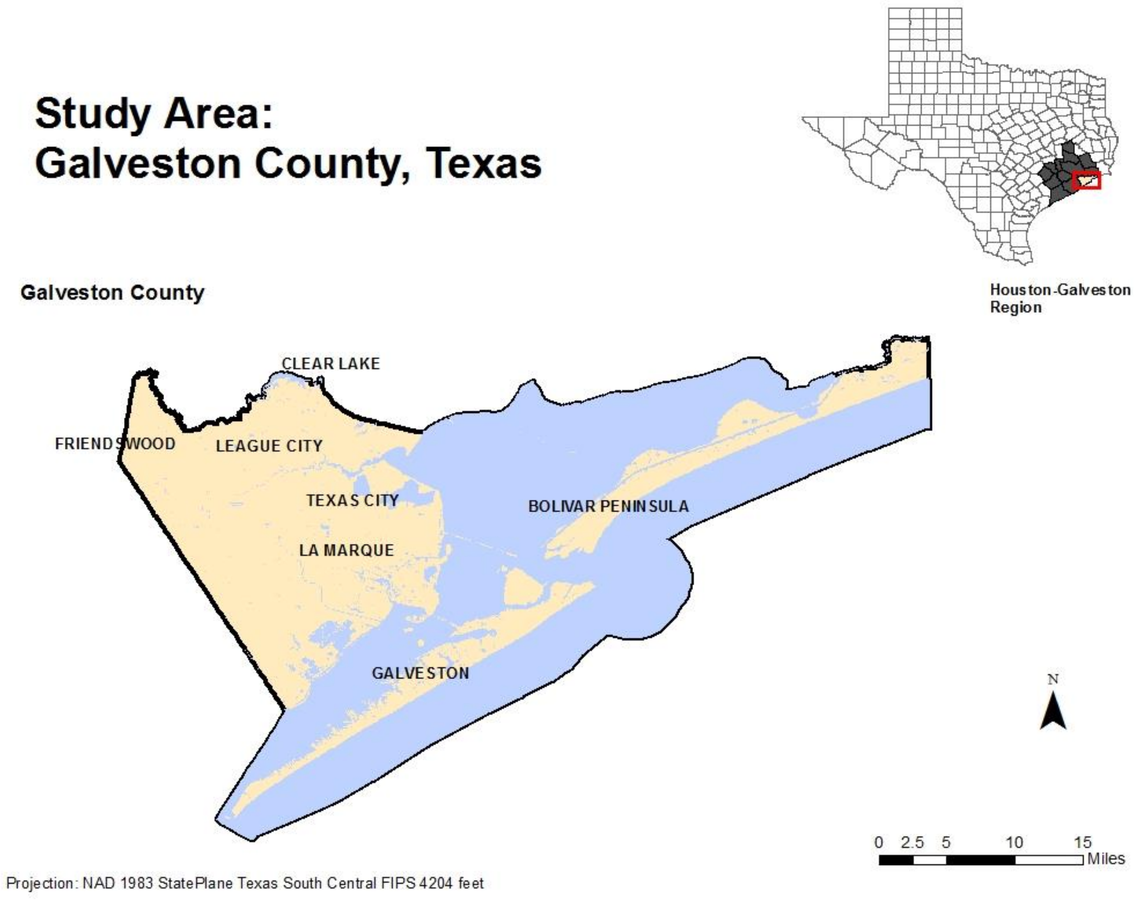
RATIONALE FOR SELECTING THE STUDY AREA

Galveston County, Texas, shown in Figure 1, has been chosen as the study area for this analysis. Galveston County is an inherently vulnerable coastal county that is challenged by rapid population growth, rising flood losses, and a state-wide planning regime that is heavily based on private property rights. In terms of population growth, the Houston-Galveston area is one of the three locations (including Corpus Christi and Brownsville) along the Texas coast that has experienced significant population increases.[8] Currently, the region is one of the fastest growing regions in the US with an anticipated population increase of over 40 percent between 2000 and 2015.[9] In addition, Federal Emergency Management Agency's (FEMA) statistics on flood insurance payments from 1978 to 2001 ranks Texas as the state with the highest number of deaths (twice the total for California, the second highest state) and most insurance losses per year from flooding.[10] It is Texas' coastal counties such as Galveston County which heavily contribute to these annual losses. Lastly, Texas does not have a statewide planning mandate which leaves the responsibility of voluntary land use planning up to

[8] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)
[9] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)
[10] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

authorized localities.[11] All in all, Galveston County is an intriguing geography for the assessment of coastal flood vulnerability, and is a location that has a great opportunity to address its vulnerability through resiliency building.

Figure 1: Research Study Area of Galveston County, Texas



[11] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

Chapter 2: Resilience and the Complexities of a Changing World

Resilience

Resilience speaks to the ability of a system to easily recover from a disturbance, and highlights both flexibility and adaptability in the face of a crisis. To that end, a resilient system maintains durability to changing stimuli and unexpected circumstances.[12] Resilience allows for a system to be both strong and flexible.[13] Critical to resiliency is the intentional and anticipatory nature of its planning and forward thinking; "while much cannot be known about future events, much can be anticipated, and planning ahead becomes a key aspect of resilience."[14] The unpredictability of our world calls for the development of a system that is able to accommodate change while maintaining composure. Godschalk argues, "if we knew exactly when, where, and how disasters would occur in the future, we could engineer our systems to resist them;" however, the future is not that foreseeable. Additionally, both people and property fair better in communities that are designed for flexibility and adaptability rather than in places less prepared for unpredictability.

Complexities of Social and Ecological Resilience to Hazards

Sustainability and resiliency hinge on the dynamic and balanced interaction of the social and ecological realms. The interaction that occurs between human development and natural systems plays a truly fundamental role in defining the impacts felt from

[12] (Paton and Johnson 2006)
[13] (Godschalk 2003)
[14] (Beatley 2009)

natural processes, hazards and disasters.[15] Destruction occurs when human settlement is placed without consideration of these natural conditions. To date, most planning and development along coastlines that are fundamentally exposed to a variety of hazards has continued with "limited understanding of the long-term (or even short term) risks and dangers of living in coastal environments."[16] When human development decisions are void of ecological implications, what results are social repercussions that include loss of property, and worse, the loss of life.

Resilience also has a great deal to do with adaptability. Patron defines resilience as "the measure of how well people and societies can adapt to a changed reality and capitalize on the new possibilities offered."[17] In essence, a resilient system is one that can absorb disturbance while retaining its basic structure and emerging into a stronger, more fit and flexible form. A resilient system is not one that returns back to an equilibrium after a disaster, but evolves into a new, more adaptive state. As stated, adaptation plays a key role in increasing the flexibility of human systems and limiting risk. Adaptation is the ability for a system to adapt to change by developing new methods to absorb new and unexpected stimuli and remain functional. Inherent in the definition of adaptation is the creation of new techniques that allow a system to better respond to a changing world. Climate change is a perfect example of the wide-ranging, unprecedented change our world will confront. In the face of this anticipated yet undefined change, our human and ecological systems must learn how to adapt.

[15] (Paton and Johnson 2006)
[16] (Beatley 2009)
[17] (Paton and Johnson 2006)

Lastly, a key aspect of adaptability is the notion of redundancy, or built-in repetition which allows for more accommodation of unpredictable disturbances. If human systems seek to have a similar capacity to adapt as natural systems do, we need to identify which layers of redundancy will provides us with the most flexibility. Activities such as land use planning and hazard mitigation efforts are some ways in which human systems can build in layers of cushion that help us to prepare for, plan for, and manage hazards and limit losses.

SOCIAL RESILIENCE AND COMMUNITY LIFELINES

The resilience of human systems also depends on the strength of social networks and the integrity of critical community infrastructure, known as lifelines. A resilient city is comprised of "a sustainable network of physical systems and human communities."[18] In particular, social connections play an important role in urban resilience. Campanella (2006) eludes,

> "Cities are more than the sum of their buildings. They are also thick concatenations of social and cultural matter, and it is often this that endows a place with its defining essence and identity. It is one thing for a city's buildings to be reduced to rubble; it is much worse for a city's communal institutions and social fabric to be torn apart as well."[19]

Resilient cities are able to bend in the face of disasters because they are "composed of networked social communities and lifeline systems."[20] Lifeline infrastructure plays an essential role in supporting social networks and their community ties. This infrastructure

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[18] (Godschalk 2003)
[19] (Campanella 2006)
[20] (Godschalk 2003)

supports communities by providing “circulation of people, goods, services and information, upon which health, safety, comfort and economic activity depend on.”[21] Lifeline infrastructure includes water supplies, transportation systems (air, road, rail, and water), utilities (gas and electricity), telephones and sanitary drainage (sewage and stormwater). In addition, critical facilities include schools, churches, fire and police stations, and health centers (hospitals, trauma centers, nursing homes). For lifelines and critical facilities in coastal communities to be resilient, they must be able to weather severe storm events with limited damage, minor to no service disruption, and have a speedy return of service.[22] With day-to-day activities being conducted through and supported by this infrastructure, it is the damage to these community lifelines during natural hazard events which leave communities even more vulnerable. Ultimately, the consideration of where critical infrastructure is placed with respect to natural hazards in large part determines how resilient a community will be in the face of hazard and disaster events.

[21] (Paton and Johnson 2006)
[22] (Beatley 2009)

Chapter 3: Factors that Influence Coastal Flooding

Understanding the factors or drivers that cause flooding is an important practice for coastal communities that are plagued by this hazard. The importance of understanding the underlying causes of flooding events should not be understated; it is these causes that are critical to identify and remedy if risk is to be reduced, and resiliency is to be achieved. Along the Texas coast, both human-built and ecological variables are responsible for serious flood events; sprawling development patterns that result in increasing impervious coverage, growing floodplain area, variable soil permeability and wetland loss all contribute to the severity of flood events experience in Texas and especially in Galveston County.

BUILT ENVIRONMENT CHARACTERISTICS

Impervious Coverage

The ever-changing built environment and local land use patterns play a significant role in promoting flood risk in urban and suburban communities. In general, the increase in development intensity and therefore impervious coverage results in increased surface runoff, flooding and resulting economic losses due to exacerbated flood events.[23] Brody et al (2012) has found that impervious cover is a major factor when considering built environment elements that are responsible to flooding. In addition, specific configurations of impervious surfaces and land cover can contribute to a community's

[23] (Brody, Kim and Gunn 2012)

flood resilience as much as the baseline environmental conditions such a precipitation, soil porosity, and topography do.[24]

Impervious surfaces, impermeable materials such as pavement and even highly compacted soil made suitable for urban development, interfere with the natural drainage of a site by reducing the infiltration of runoff. The increase of impervious surface increases the surface runoff directly into stormwater systems and/or receiving bodies of water. Reduction in the infiltration capacity of a site due to the increase in impervious cover also decreases the filtration of stormwater runoff that occurs in the infiltration of runoff through soil. Figure 2 depicts how the percentage of infiltration changes with increased development and impervious cover. There are empirical and simulated studies suggesting that impervious coverage causes a substantial increase in surface runoff which escalates the frequency and severity of flooding in vulnerable areas by increasing the peak discharge during rainfall events.[25] Brody et al. (2008) determined that across 37 coastal counties in Texas and Florida, every square meter of additional impervious surface translated into approximately $3,602 of added property damage caused by floods annually. This evidence suggests that open space, wetlands and other forms of pervious surface help to mitigate flooding events, in turn ensuring some resiliency for areas that maintain permeable surfaces.

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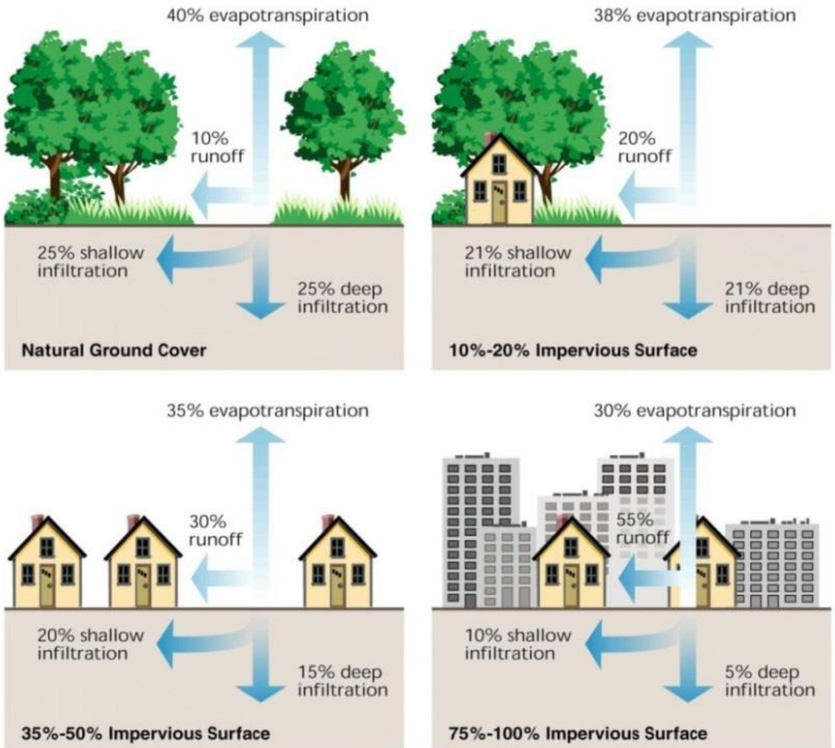
[24] (Brody, Kim and Gunn 2012)
[25] (Brody, Kim and Gunn 2012)

Figure 2: Impervious Cover Model[26]



The mere intensity of development and impervious cover does not entirely describe a community's vulnerability to flooding; it is the pattern of this development with respect to vulnerable areas which more closely defines the exposure to flood risk.[27] High intensity development that is built well outside of the 100-year floodplain may be more resilient to flood risk than low intensity development. While low-density development patterns contain less impervious cover, the disaggregation of development among flood prone areas may compromise hydrological systems and cause this development to be more vulnerable to flooding.

26 (Impervious Cover Model n.d.)

27 (Brody, Kim and Gunn 2012)

NATURAL ENVIRONMENT CHARACTERISTICS

Floodplain area

To better understand flood risk, it is also necessary to analyze our conventional means for conceptualizing and delineating flood risk. Flood risk is based upon the 100-year floodplain which signifies a one percent risk of flooding per year. It is the most persistent metric and indicator for determining flood risk. The 100-year floodplain is used as the spatial delineation by FEMA in the National Flood Insurance Program (NFIP); it guides local planning and development decisions as well as insurance purchases and other household adjustments.[28] The 100-year floodplain is the basis for the creation of Flood Insurance Rate Maps (FIRMs). FIRMs are created through NFIP and determine, based upon floodplain boundaries, how flood insurance is managed. Flood insurance is a required purchase of all development that lies within the designated 100-year floodplain; development that lies outside of this boundary, to any degree, does not have the same requirement.

This strict delineation of flood risk based upon the 100-year floodplain boundary is problematic in several ways. Firstly, emerging evidence suggests that the 100-year floodplain may not accurately delineate flood risk. The use of the 100-year floodplain as a dichotomous boundary views development outside of the floodplain, whether it lies one foot or one mile outside of the boundary, with having limited flood risk.[29] The reality is that flood risk is still very present in the areas adjacent to the 100-year floodplain

[28] (Brody, Blessing, et al. 2012)
[29] (Brody, Blessing, et al. 2012)

boundary, and the idea that floodplains clearly delineate flood risk creates a false sense of security from flood risk.

Secondly, 100-year floodplain boundaries themselves are becoming less reliable in determining flood risk. The inaccuracy of floodplains is in large part due to natural and human influences which cause local landscapes to evolve more quickly than then floodplain boundaries can be revised; Urban and suburban developments are changing landscape conditions at such a rate that FIRMs are not able to reflect the true risk of flooding to households. What is so problematic about the inaccuracy floodplains and FIRMS is that they are "translated into 'dichotomous decisions' that determine where development must be restricted, plans made, and [flood] insurance purchased."[30] The inaccuracy of FIRMs results in a population of households and development that lie slightly outside of the floodplain boundary which may be exposed to as much flood risk as those within the floodplain boundary, yet are not eligible for federal flood insurance nor are communicated to about the risk.

FEMA has started to address the inaccuracy of flood maps through their Map Modernization Management Support (MMS) program which works to update floodplain maps. While these updated floodplains and FIRMS are clarifying some of the risk ambiguity found in the earlier maps, they still do not capture how future growth and development patterns will change flood risk.[31] This poses a challenge for the relevancy

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30 (Highfield, Norman and Brody 2012)
31 (Highfield, Norman and Brody 2012)

of these updated maps in the near future due to the continued urbanization of our physical landscape.

Soil Porosity

Soil Porosity is another important indicator used in determining a community's vulnerability to flooding. Soil porosity describes the rate of infiltration, or the speed with which water moves through soil media. Soils allow liquids to permeate more or less quickly based on the soil texture and its current moisture saturation.[32] In general, more porous soils contain a high sand content which allow water to filter through the soil rather quickly, allow for more storage and result in less runoff.[33] Less porous soil can result in higher peak and mean annual flows within a given watershed. Well-drained soils play a critical role in reducing stormwater run-off and associated flood damage. Therefore, soil structures near 100-year floodplain boundaries should be considered an important indicator for describing vulnerability to flooding that could potentially impact property and lives.[34]

Wetlands

Wetlands also play a key role in providing ecosystem services, especially flood mitigation to communities. Acting like a sponge, naturally occurring wetlands provide infiltration capacity to both reduce and slow heavy rainfall and flooding events as well as

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32 (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

33 (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

34 (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

mitigation against storm surge impacts from hurricanes and severe storms. The loss of wetlands has shown to be disastrous for flood prone communities. Brody et al. (year) found that the loss of wetland across 37 coastal counties in Texas from 1997 to 2001 significantly increased the amount of property damage as a result of floods; therefore, the assumption is that the loss of wetlands will result in exacerbated flooding.[35]

Research using simulation models has shown that the removal of wetlands has resulted in more exacerbated flood events. A particular simulation model created by Ogawa and Male in 1986 evaluated the role of wetlands in reducing flooding; their research included four scenarios that simulated development encroachment on 25 percent to 100 percent of downstream wetlands. They found that peak flow of flooding events increased with higher encroachment.[36] Other preliminary research suggests that wetlands have a critical threshold for their ability to attenuate flooding; if too much of a given wetland has been lost, it can no longer serve its flood mitigation purposes.[37] There is additional evidence that has shown that even a relatively small loss of wetlands greatly impacts flood outcomes.[38]

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[35] (Brody, Blessing, et al. 2012)

[36] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

[37] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

[38] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

Chapter 4: History of Galveston County and Its Vulnerability

Galveston County is comprised of mainland Galveston and Galveston Island which is separated from the mainland by Galveston Bay. Galveston County has nine cities which include Bayou Vista, Clear Lake Shores, Dickinson, Galveston, Hitchcock, Jamaica Beach, Kemah, La Marque, and Village of Tiki Island. Galveston County exists as a particularly vulnerable location to flood risk from rain and severe storm events. Galveston Island is located on the plains of the Texas Gulf Coast and the northwest coast of the Gulf of Mexico. The island lies 50 miles southeast of Houston, Texas. Galveston varies in width from one and one half miles to three miles in width, and is 27 miles long.[39] Like many of the islands along the Texas Gulf Coast, Galveston Island is a sand barrier island protecting mainland Galveston County.[40] The soil on the mainland of Galveston County has relatively poor drainage due to the heavy clay subsoils which remain saturated for long periods of time.[41] As a result, Galveston County has had long-standing drainage and flood control problems. In addition, the high salt content of Galveston's soils has prevented the county to be agriculturally productive. Galveston Bay, located 30 miles north of Galveston Island is the drainage basin for numerous small creeks and rivers including: Dickinson Bayou, Clear Creek Bayou, Buffalo Bayou, San Jacinto River, Cedar Bayou and Trinity River. The mud flats and salt marshes which border Galveston Bay and northern part of Galveston Island are remarkable in their ecological productivity. The marsh is noted as being "intensely alive;" a Rice University

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[39] (McComb 2008)
[40] (McComb 2008)
[41] (McComb 2008)

report on the ecological productivity of the East Bay wetlands explains that an acre of marsh produces ten times more protein than an acre of farmland.[42] The plants in the marsh environment serve key biological functions of productivity and protection. The natural protective function of Galveston's marsh and wetland area plays an important role in demonstrating the natural defenses that the land form of mainland Galveston and Galveston Island have.

Galveston County was originally founded in 1838 under the Republic of Texas; during that time, Galveston Island and the City of Galveston was the most important population center in Texas. The strategic location of Galveston Island formed a natural harbor which was deemed the best natural port between New York and Vera Cruz for safe docking of vessels in the 19th century.[43] When Texas entered into annexation with the United States in 1885, it was Galveston that played an essential role in the presence of the United States in the worldwide cotton commerce.

Galveston's natural port and strategic positioning on the Gulf of Mexico has had both fortunate and unfortunate connotations for the island. The Island's strategic positioning within the Gulf of Mexico has exposed Galveston to severe weather that moves through the Gulf of Mexico. It was the massive devastation from the Hurricane of 1900 which showed the true vulnerability of Galveston. The Hurricane of 1900 still stands as the deadliest storm to ever hit the United States. 8,000 people were killed after a destructive 15 foot storm surge, a volume of water that is pushed ahead of a tropical

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[42] (McComb 2008)
[43] (McComb 2008)

cyclone as it makes landfall, washed over the island.[44] It is estimated that the damage totaled to $30 million based on non-adjusted inflation dollars.[45] The storm "not only changed the history of the island, but the economy and population of Texas, because most of the shipping activity was moved to the Port of Houston after the event."[46] In addition, the 1901 discovery of oil at Spindletop in Beaumont and the dredging of the Houston Ship Channel in 1909 solidified the emergence of Houston, not Galveston as Texas' new center of commerce.

Following the storm, the recovery of Galveston Island after the 1900 Hurricane called for the implementation of structural mitigation to defend the island from threat of storm surge. Firstly, dredged sand was used to raise the island by 17 feet. Secondly, a 17 foot height, 27 foot wide, and three mile long granite boulder seawall was constructed on the southern side of the island to provide additional protection to downtown Galveston.[47] In 1962, the Galveston Seawall was extended even farther to provide additional protection from storm surge. The seawall has proven successful in protecting Galveston from the hurricanes that have passed through Galveston, including in 1915, 1932, 1949, 1983, and 2008 with the arrival of Hurricane Ike.[48]

Hurricane Ike made landfall in September 13, 2008 as a Category 2 storm with a size that resembled closer to a Category 4 storm.[49] Hurricane Ike is the costliest and most damaging storm to hit the Texas coast since the 1900 Hurricane; with 103 deaths and

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44 (Bedient 2012)
45 (Bedient 2012)
46 (Bedient 2012)
47 (Bedient 2012)
48 (Bedient 2012)
49 (Bedient 2012)

damages totaling to $24.9 billion, Hurricane Ike ranks as the third most costly storm in US history (without considering damages resulting from Hurricane Sandy).[50] The storm's most destructive element was again the storm surge which resulted in extensive flooding along the island and mainland Galveston. The destruction wrought by the storm surge resulted in homes that were flooding, homes ripped from their foundations, eroded beaches, and a large population of live oak trees that perished due to saltwater intrusion.[51]

GEOPHYSICAL PROFILE OF GALVESTON COUNTY

The dominant land use and land cover categories in Galveston County are open water, wetlands, and farm-ranch land. Comparatively, the percentage of developed land cover/land uses comprises a relatively small amount of the county's overall land cover and land use. Maps of land cover and land use as well as corresponding percentages of the respective categories can be referenced in Figures 3-6. The developed land within Galveston County occurs in specific nodes; therefore, the percentage of imperviousness found in Galveston County occurs in several concentrated nodes. Figure 7 depicts the imperviousness across Galveston County; in general, the clusters of high imperviousness are concentrated in Friendswood, League City, Clear Lake, Texas City, La Marque, the East End of Galveston Island, and along Bolivar Peninsula. Lastly, soil porosity, which can be referenced in Figure 8, shows that mainland Galveston contains relatively permeable soil with the shoreline of Galveston Bay shoreline containing moderately less permeable soils. Bolivar Peninsula contains patches of the most permeable soil with

[50] (Bedient 2012)
[51] (Bedient 2012)

some moderately permeable soil along the Galveston Bay shoreline. Finally, Galveston Island contains the least porous soil within Galveston County.

Figure 3: Land Cover for Galveston County

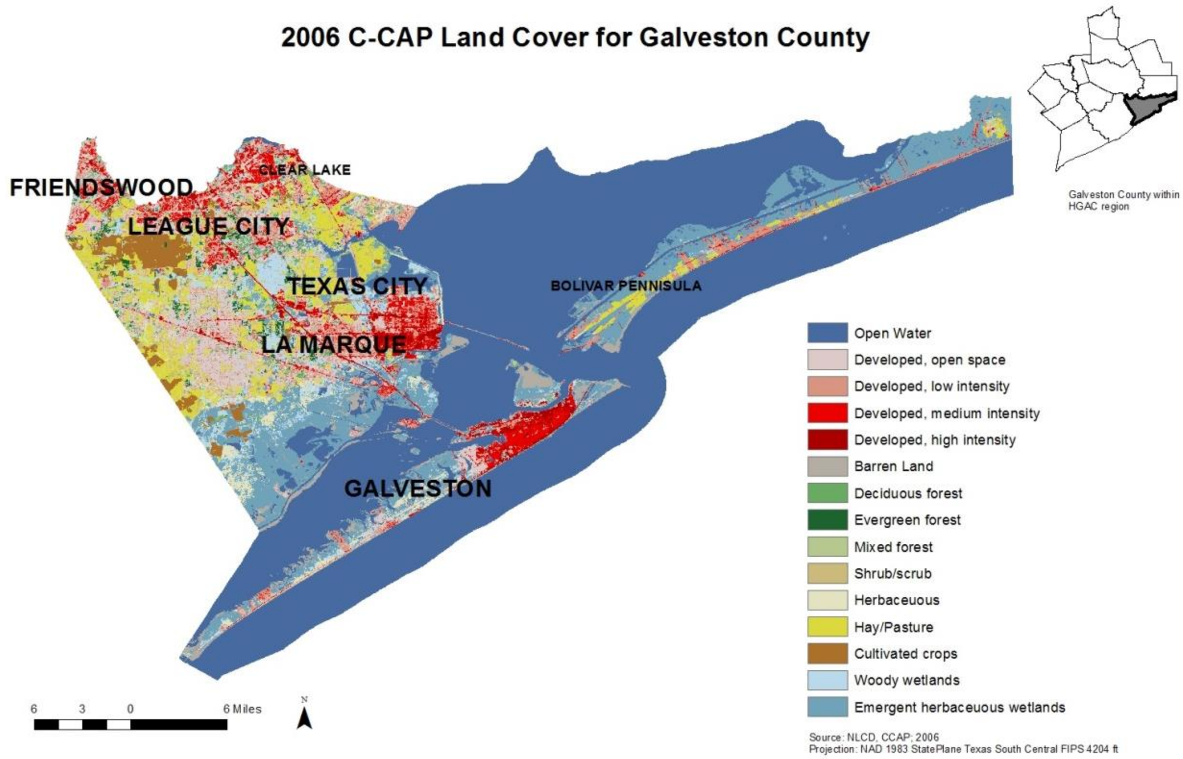


Figure 4: Land Use for Galveston County (2010)

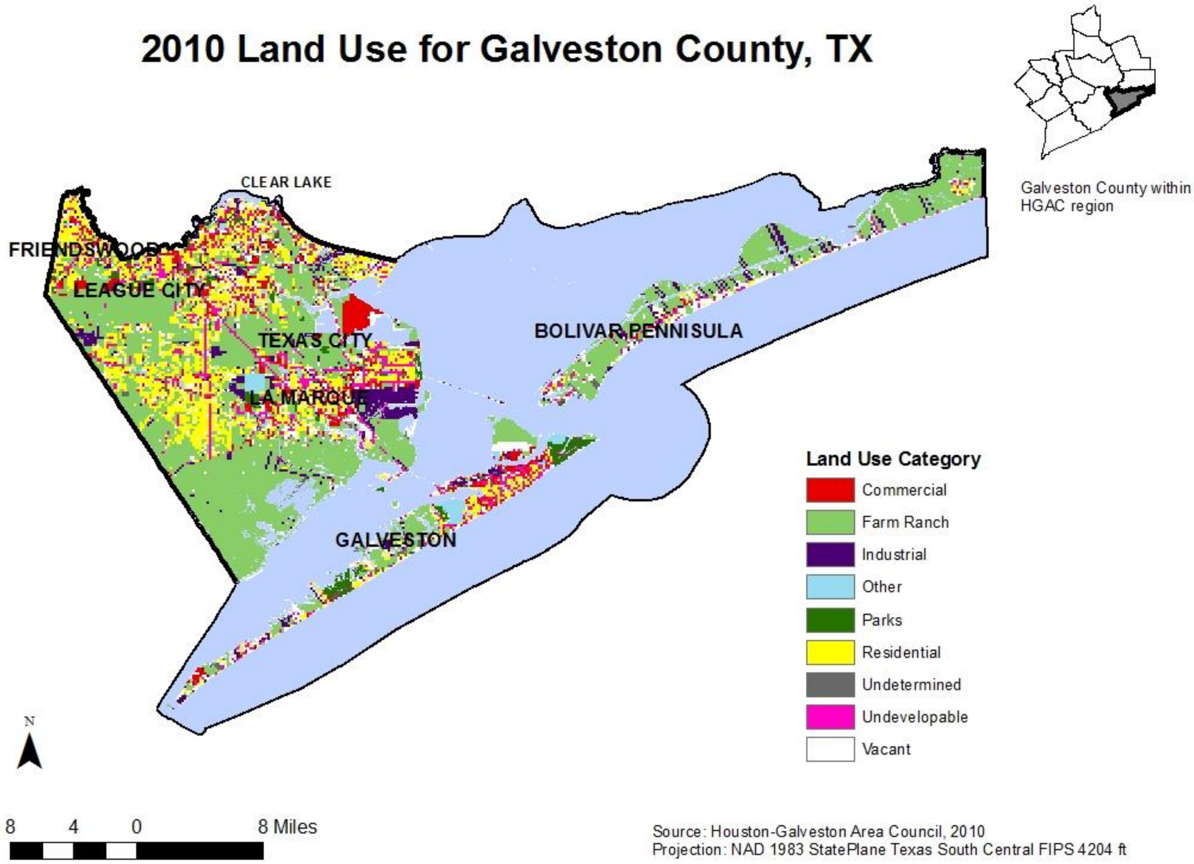


Figure 5: Percentage of 2006 Land Cover Types

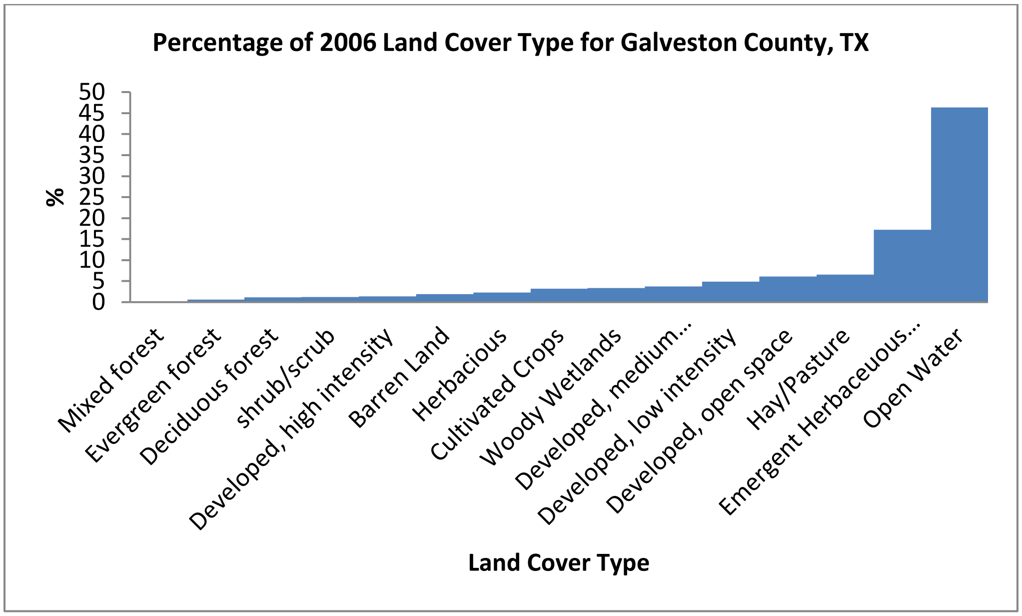


Figure 6: Percentage of 2010 Land Use Type

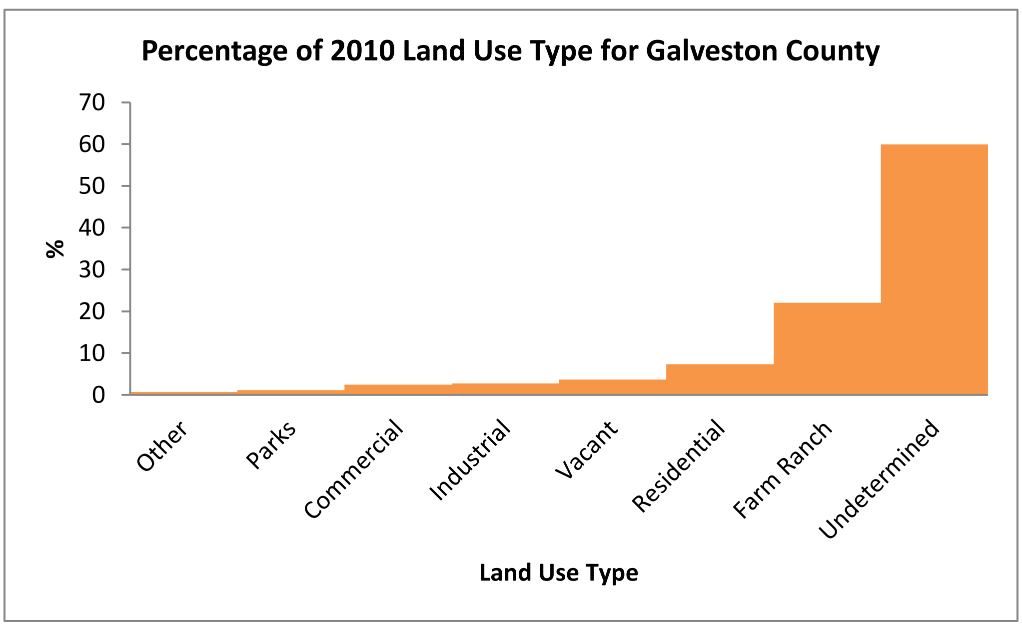


Figure 7: Percentage of Imperviousness

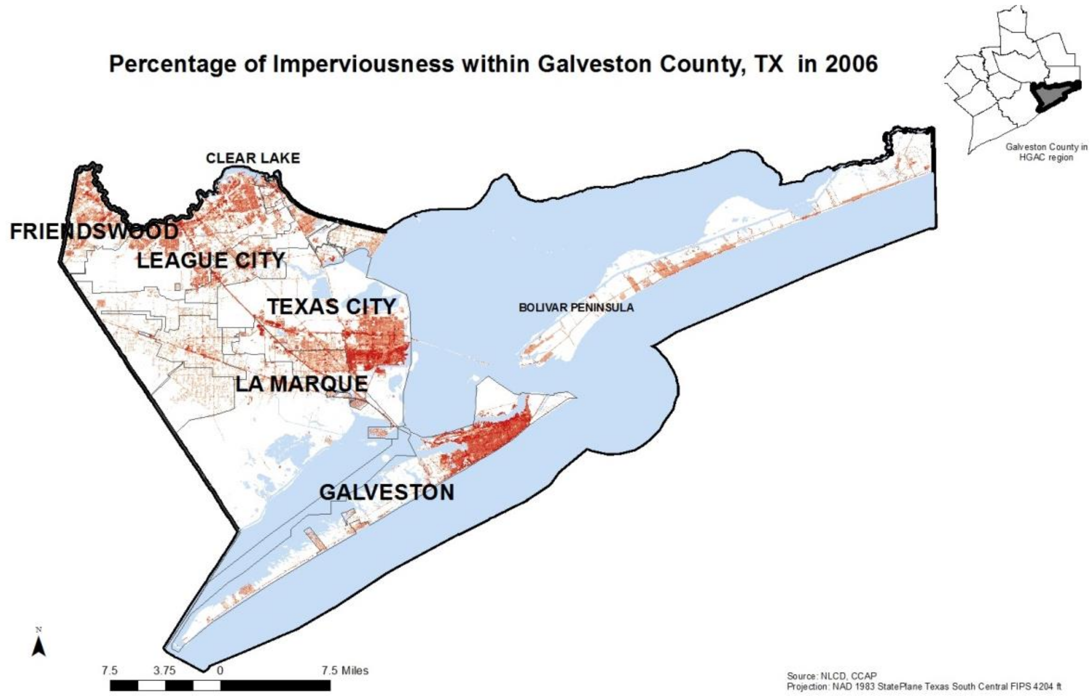
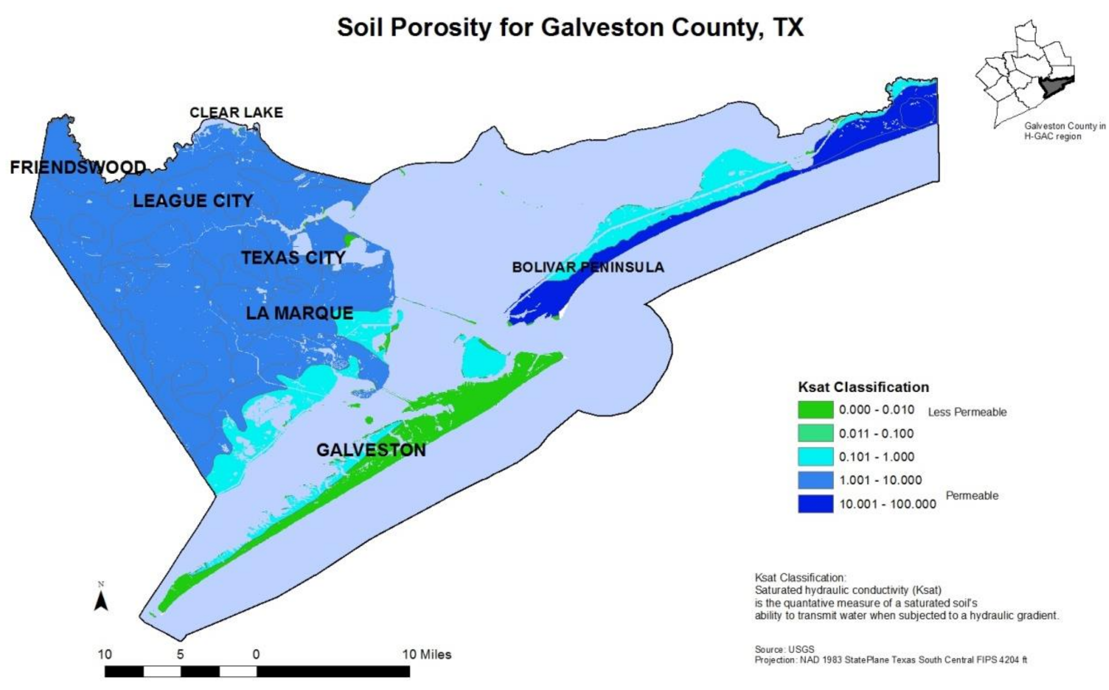


Figure 8: Soil Porosity



Chapter 5: Creation of Vulnerability Index to Flood Risk in Galveston County

Research Questions

This research seeks to spatially analyze several geophysical and development elements that contribute to flood vulnerability. My research questions ask:

1) How our development patterns accentuate vulnerability to flood risk in the coastal county of Galveston County?
2) Where the critical infrastructure elements of the built environment are located with respect to this vulnerability to flood risk in Galveston County?

The vulnerability of critical infrastructure to flood risk speaks to the degree of community vulnerability in the face of severe storm and flooding events. The goal of this research is to understand how much of Galveston County's built environment is vulnerable to flood risk as well as what critical infrastructure is most vulnerable to flooding. Ultimately, this research seeks the creation of a vulnerability index to flood risk that can shed light on the way in which land use and emergency management planning can limit future flood risk and increase coastal resilience in Galveston County.

Analysis and Creation of Vulnerability Index to Flood Risk

The goal of this analysis is to create a vulnerability index to flood risk based on geophysical and built environment elements of Galveston County. This physical vulnerability index to flood risk will complement the extensive social vulnerability index created for the Texas Sustainable Coastal Initiative's Texas Coastal Planning Atlas which is maintained by Texas A&M University. The scale of this analysis is based on both parcels and block groups within Galveston County. Choosing these geographies allows this analysis to be performed at a finer scale to analyze coastal vulnerability in more detail than previously documented in the Texas Coastal Planning Atlas. Another important aspect of this analysis is its replicability. This vulnerability index will be replicated for Brazoria County and provides a framework for the analysis of physical coastal vulnerability for other coastal communities.

Index Variables and Justification for Their Use

There are four data layers that were used to describe physical vulnerability to flood risk in Galveston County. These data layers consist of the 100-year floodplain, Category 1 hurricane storm surge zone, soil porosity, and percentage of impervious cover. Table 1 further explains the data.

Table 1: Variables within the Vulnerability Index to Flood Risk

Variable	Source
Natural Environment Variables	
100-year floodplain	FEMA
Category 1 hurricane storm surge	FEMA
Soil porosity	USGS
Built Environment Variables	
Percent of Impervious Cover	NLCD

The above variables were chosen because they characterize important aspects of the natural and built environments which contribute to flood risk. The 100-year floodplain and the Category 1 hurricane storm surge were chosen as variables because they are established high flood risk zones. Soil porosity was the next variable chosen because it communicates the speed with which the soil can drain water given a flooding event; a location that has less permeable soil and is located within high risk flood zones has an increased vulnerability to flood risk. Lastly, the percentage of impervious surface was chosen to represent the location of the built environment. Figures 9-12 depict the spatial layout of these variables within Galveston County.

Figure 9: 100-year Floodplain in Galveston County

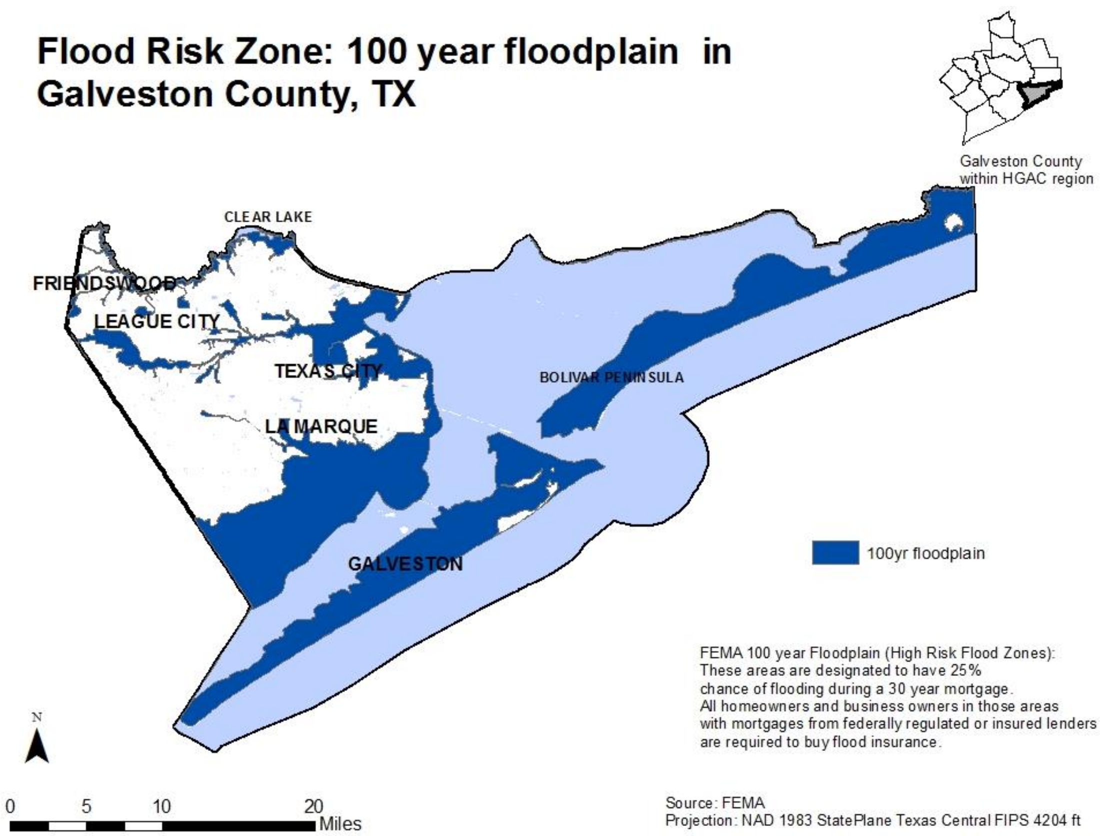


Figure 10: Category 1 Hurricane Storm Surge in Galveston County

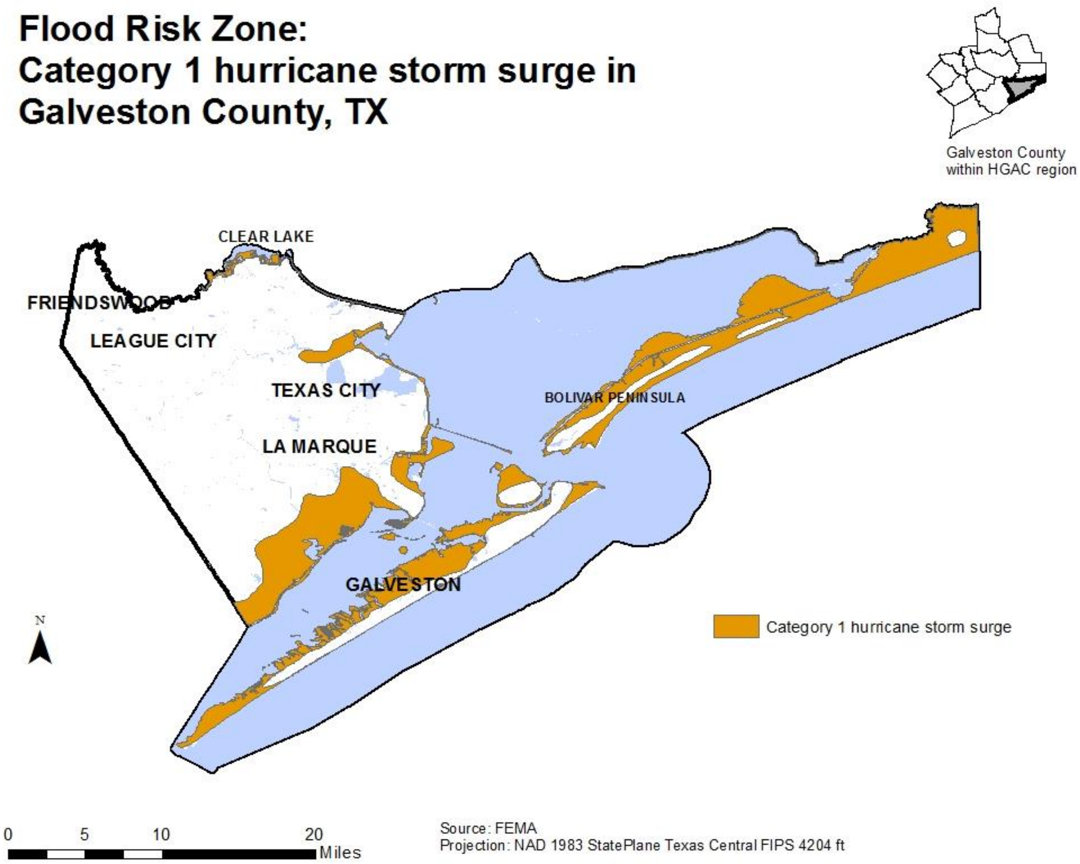


Figure 11: Soil Porosity for Galveston County

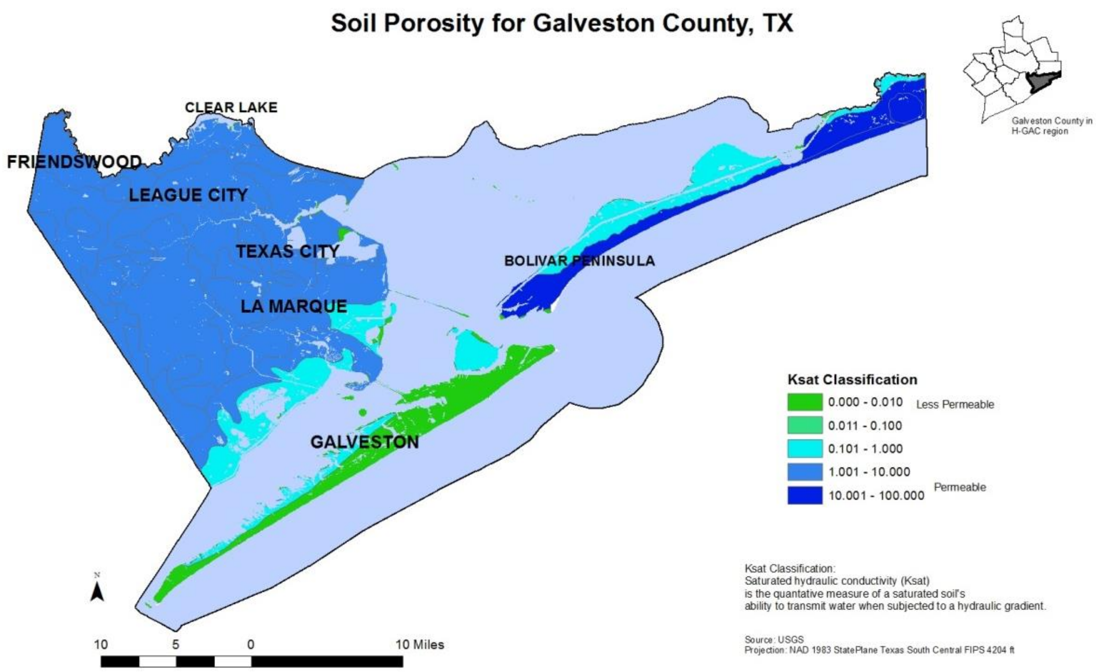
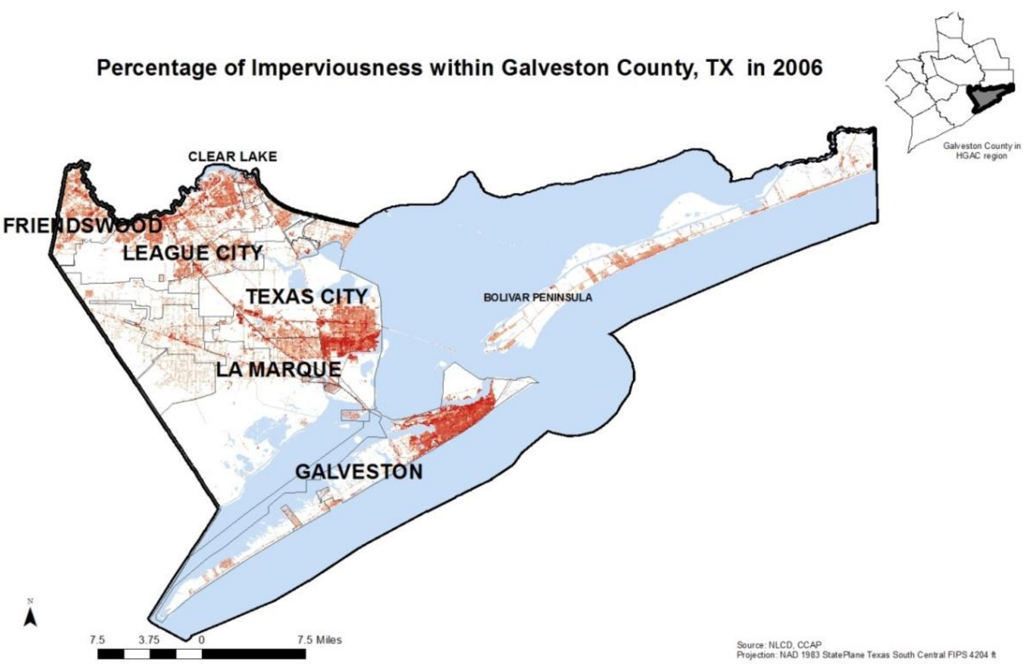


Figure 12: Percentage of Imperviousness within Galveston County



Creation of the Vulnerability Index to Flood Risk

The first steps in the creation of the vulnerability index involved GIS geoprocessing and projecting of the data layers. All of the data layers were clipped to the Galveston County boundary and then projected to NAD 1983 StatePlane Texas South Central FIPS 4204 feet projected coordinate system. Next, all data layers were rasterized according to an output cell size of 100 feet. It was important that the output cell size that was chosen was small enough to analyze the average size of parcels within Galveston County. Next, the euclidean distance was calculated for the 100-year floodplain and Category 1 hurricane storm surge. Euclidean distance is an ArcGIS function that calculates the average distance from each cell in the raster from the closest source, which in this analysis was the 100-year floodplain and Category 1 hurricane storm surge respectively. The calculation of proximity to the flood risk zones better communicates the range of vulnerability to flood risk, rather than the binary determination of being inside or outside these flood risk zones.

Once all data layers were rasterized, the Z-score, or standard score was calculated for each layer using the Raster Calculator in ArcGIS. The equation used to calculate Z-score can be referenced in Equation 1. Z-score represents the number of standard deviations a datum is above or below the data's mean.

Equation 1: Z-score

$$Z - score = \frac{(X - mean)}{standard\ deviation}$$

The Z-score calculation for each layer was an important step because it allows the different data layers to be compared on the same universal scale based on standard deviations. The Z-score for each layer essentially creates a range, from high to low, of vulnerability based upon the standard deviations from the mean within each data layer. The means and standard deviations for the data layers are then compared on a relative vulnerability scale for Galveston County. This aspect of relativity is important as Galveston County is already a vulnerable location; this vulnerability index has been created relative to the existing and acknowledged vulnerability to flood risk of Galveston County.

An important step before the Z-scores could be added in Raster Calculator to create the index was to make sure that the range of vulnerability for each data layer was correctly portraying high and low vulnerability. Table 2 depicts the range of vulnerability used for each data layer.

Table 2: Range of Vulnerability Established for Each Variable within Vulnerability Index

Variable	**Low Vulnerability**	**High Vulnerability**
Euclidean Distance from 100-year floodplain	Distance farther away	Distance closer to
Euclidean Distance from Category 1 hurricane storm surge	Distance farther away	Distance closer to
Soil Porosity	More permeable soil (high Ksat value)	Less permeable soil (low Ksat value)
% Imperviousness	Low % imperviousness	High % imperviousness

Once all there was universal correspondence of the Z-score ranges, the Raster Calculator was used to add up the Z-scores to create the additive vulnerability index to flood risk within Galveston County. To apply the vulnerability index to the scale of parcels and block groups, the ArcGIS zonal statistics tool (based on the mean) was used to apply the vulnerability index to the county's block groups, parcels, and parcels that contain critical infrastructure. The application of the vulnerability index to the county's block groups allows for this vulnerability index to flood risk to be used on the Texas Coastal Planning Atlas and overlapped with existing social vulnerability index which is also based on the block group level. The coupling of this index with the social vulnerability analysis allows for a comprehensive assessment of coastal vulnerability within Galveston County to be performed.

On the other hand, the application of the vulnerability index on the parcel level provided an even finer level of analysis of vulnerability with respect to the built environment in Galveston County. In addition, the use of the parcel data enabled the vulnerability index to also be applied to the parcels that contain critical infrastructure. For this analysis, critical infrastructure is comprised of schools, churches, health centers, and utilities as depicted by land use codes assigned by Galveston County Appraisal District. Table 3 includes the full list of critical infrastructure selected from the land use codes on the Galveston County parcel data. The three most prominent forms of critical infrastructure within Galveston County are tax-exempt commercial (schools, churches, and healthcare centers), electric companies, and telephone companies.

Table 3: List of Critical Infrastructure by Land Use Code

Land Use Code	Land Use Description	Count of Land Use within Parcels with Critical Infrastructure	% Land Use within Parcels with Critical Infrastructure
F9	Tax-exempt commercial (schools, churches, healthcare centers)	1204	78.3%
J1	Real/tangible personal utilities/ water systems	3	0.2%
J2	Gas companies	9	0.6%
J3	Electric companies	290	18.9%
J4	Telephone companies	18	1.2%
J5	Railroads	5	0.3%
J6	Pipelines	4	0.3%
J9	Tax-exempt personal utilities/water systems	5	0.3%

By applying the vulnerability index to the parcels that contain this critical infrastructure, an important characteristic of community vulnerability to flood risk is uncovered. By being able to identify the parcels with critical infrastructure which are the most vulnerable to flood risk, the most threatened community lifelines are identified. It is the hope that planners and emergency managers can use this vulnerability index to flood risk applied to block groups and parcels to focus their attention on better protecting this infrastructure and the communities it serves.

Chapter 6: Results of Vulnerability Index to Flood Risk

The Vulnerability Index applied to Galveston County on the block group and parcel level shows that are five main clusters of high vulnerability to flood risk. These high vulnerability clusters occur in Clear Lake, Texas City, La Marque, East End of Galveston Island, and Bolivar Peninsula. Figures 13-15 depict the vulnerability index as applied to these geographies. These locales provide important functioning to Galveston County. Clear Lake is home to NASA’s Johnson Space Center and other aerospace companies such as Boeing and Lockheed-Martin, while Texas City is a busy deep-water port that houses petroleum refining as well as petrochemical manufacturing. The City of La Marque provides general administration trade and craft to Texas City as well as housing for a large percentage of the workforce employed in Texas City’s petrochemical complex. The East End of Galveston Island contains the Port of Galveston as well as residential and commercial uses; specifically, the Port of Galveston plays an important role in the regional and national goods movement as it handles a wide range of cargo that is distributed throughout the region and nation from the Galveston Railroad. Lastly, Bolivar Peninsula is a mainly residential location in Galveston County. The application of the vulnerability index to flood risk on the block group and parcel geographies reveals that some of the most populated and economically productive locations in Galveston County are also the most vulnerable to flooding.

Figure 13: Vulnerability Index to Flood Risk in Galveston County

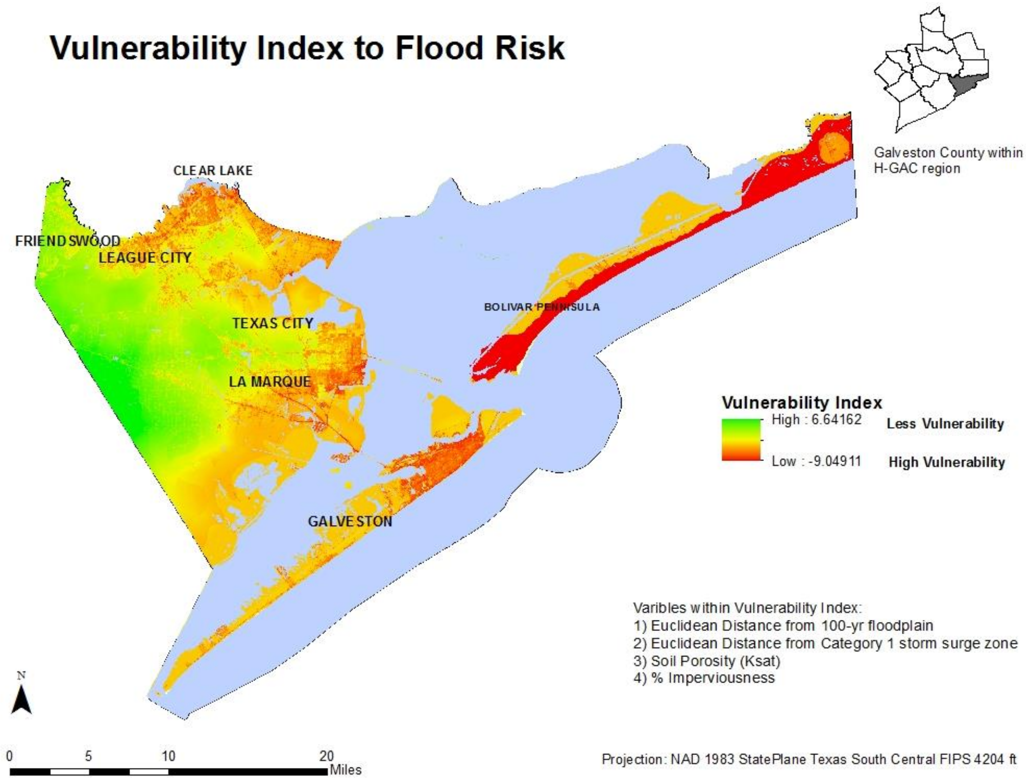


Figure 14: Vulnerability Index to Flood Risk Applied to Block Groups within Galveston County

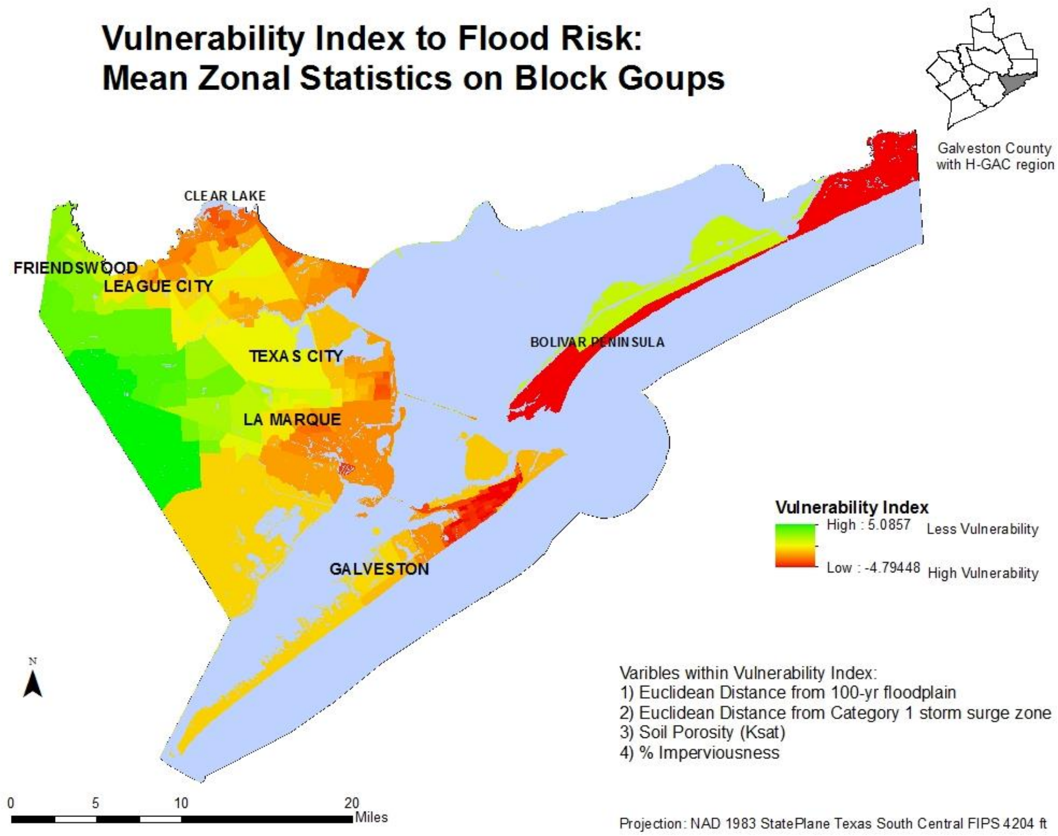
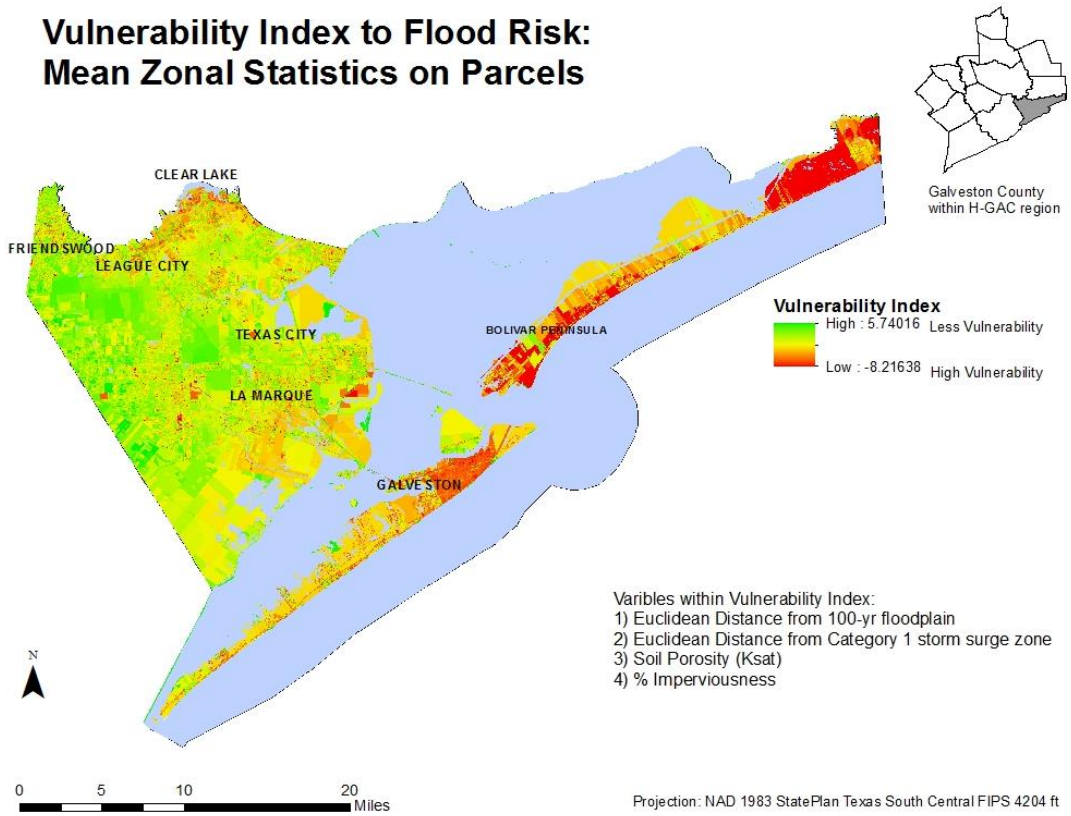


Figure 15: Vulnerability Index to Flood Risk Applied to Parcels within Galveston County



By applying the vulnerability index to the parcels that contain critical infrastructure within Galveston County, a level of community vulnerability is uncovered. Figure 16 displays the vulnerability index to flood risk applied to parcels that contain critical infrastructure within Galveston County. In general, the parcels containing critical infrastructure that are most vulnerable to flood risk are found within the high vulnerability nodes of Clear Lake, Texas City, La Marque, East End of Galveston Island, and Bolivar Peninsula.

Figure 16: Vulnerability Index to Flood Risk Applied to Parcels with Critical Infrastructure within Galveston County

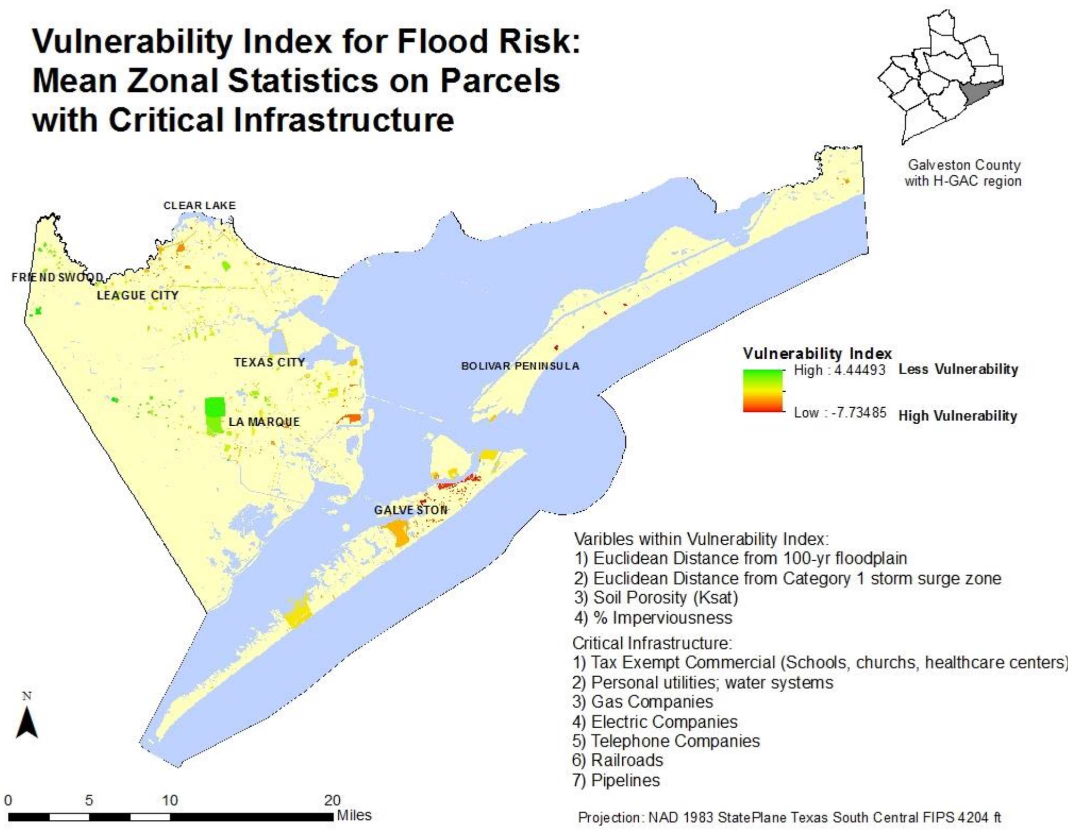


Table 4 includes a list of the general types of critical infrastructure that are found within the high vulnerability nodes. All types of critical infrastructure is exposed to high vulnerability to flood risk; city buildings, schools, churches, healthcare centers, utility lines, transportation infrastructure, and industrial infrastructure are all shown to be highly vulnerable to flood risk. The exposure to risk for this critical infrastructure speaks to the larger impacts inflicted on a community given a severely damaging flooding event. Firstly, the potential of large-scale economic impacts is communicated by the exposure of key industrial infrastructure in Texas City and Galveston Island to flood risk. Secondly, the exposure of independent school district (ISD) school buildings to flood risk communicates the threat to community schools and teachers. Lastly, the vulnerability of electric and telephone lines to flood risk highlights the threat of power outages and communication shutdown if severe flooding or storm events occur.

Table 4: Types of Critical Infrastructure Exposed to High Flood Risk in High Vulnerability Nodes

Clear Lake City buildings Churches Clear Lake ISD buildings Healthcare centers Electricity lines
Texas City City buildings Texas City ISD buildings Texas City Terminal Railway Company transportation infrastructure Churches
La Marque Churches La Marque ISD buildings Municipal Utility Districts (MUD) Electricity and telephone lines
East End of Galveston Island City buildings Churches Galveston ISD buildings City of Galveston Housing Authority buildings Texas A&M University buildings Port of Galveston Galveston County Jail Electricity lines
Bolivar Peninsula Churches Telephone lines Fire Department Water supply infrastructure Galveston ISD buildings

Interpretation of Results within Resiliency Building Framework

The results of the study indicate that Galveston County contains nodes of high flood vulnerability as a result of low soil porosity, proximity to 100-year floodplain and Category 1 hurricane storm surge zone, and high percentage of impervious coverage. Within these nodes, key elements of the county's critical infrastructure are also highly exposed to flood risk. The flexibility and adaptability of Galveston County in the face of severe flooding events is reliant upon the durability of these community lifelines and critical infrastructure. The vulnerability of critical infrastructure suggests that Galveston County has important steps to take to protect its communities and infrastructure, and ultimately build resiliency. For Galveston County to become resilient in the face of flood risk, two important questions need to be answered:

1) How will Galveston County's existing population and critical infrastructure that is already exposed to flood risk be protected?
2) How can Galveston County's future population and critical infrastructure be placed in less vulnerable locations and resiliency to coastal flooding is increased?

The answers to these questions are challenging to say the least; with the projected increase of Galveston County's population as well as a political environment that is defined by strong private property rights and therefore limited regulations on land use, Galveston County does not have an easy road ahead. Despite these challenges, Galveston County and its cities do have the ability to address their vulnerability to flooding and to build coastal resilience. There are some actions that can be taken to protect the existing population and infrastructure and can better influence the location of future development in less vulnerable locations. The policy-oriented methods of reducing vulnerability to flooding for Galveston County include coupling land use and hazard mitigation planning, implementing structural mitigation measures, and creating community-specific resiliency targets.

Chapter 7: Recommendations and Steps Forward

Coupling Land Use and Hazard Mitigation Planning

The first recommendation for addressing Galveston County's vulnerability to flood risk is through smart land use planning that seeks to mitigate the negative impacts of the flood hazard. Land use planning alone stands as an important disaster mitigation tool; it can be used to regulate the type and intensity of development in most vulnerable, flood prone areas to limit risk exposure and ultimately guide development to more appropriate locations. For many locations, land use planning is a state-wide mandate and occurs on both the county and local level. The state of Texas, on the other hand is a unique case. Texas has no state-wide zoning requirements for local planning and instead, relies on legislation that empowers cities with a population of at least 5,000, known as Home Rule cities, to create and implement any and all land use planning activities. Texas counties and jurisdictions that are smaller than 5,000 people are not able to enact zoning regulations or enforce building codes.[52] Ultimately, Texas' political structure results in land use planning that occurs solely on the local level with Home Rule cities in control of shaping their physical landscapes.

Of the five cities that show the highest vulnerability to flood risk found within Galveston County, four of these are Home Rule cities. Clear Lake, Texas City, La Marque and City of Galveston represent four of Galveston County's 12 Home Rule cities. (Bolivar Peninsula is considered a census-designated place.) As Home Rule cities, Clear Lake, Texas City, La Marque and City of Galveston have the power to implement land

[52] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

use planning strategies, and therefore, have a greater amount of influence, if exercised, on where development is allowed to go within their city limits. These cities can look to other places for examples of land use planning tools that are effective in limiting development in vulnerable locations; some of these tools include low- and no-density zoning schemes, setback requirements, transfer of development rights (TDR) programs, and conservation easements. The drawback to these land use tools is that they are best implemented when natural hazard areas such as coastal areas or 100-year floodplains are not extensively built out. With a developed and developing coastline and floodplain area, Home Rule cities within Galveston County will need to become more creative with implementing land use activities that can balance development pressures while limiting current and continued exposure to flood risk.

One option for Clear Lake, Texas City, La Marque and City of Galveston is to couple land use planning strategies with other mitigation techniques to more effectively reduce vulnerability of coastal populations and its infrastructure. Linking land use planning and hazard mitigation efforts provides localities with the opportunity to deter further development of the county's most vulnerable locations by focusing on the implementation of mitigation measures that protect the most exposed population and critical infrastructure. Hazard mitigation includes a collection of actions which reduce and eliminate long-term risk to populations and property from hazards; these mitigation measures range from structural solutions such as engineered levees and building code standards to land use planning and building acquisition in flood prone areas.

The coupling of land use planning and hazard mitigation measures is a functional step in Galveston County as both of these efforts are coordinated on the local level. Similar to land use planning that occurs within Galveston County, the majority of hazard mitigation planning happens within Home Rule cities. Each Home Rule city has an assigned emergency manager who coordinates the city's own hazard mitigation plan which often is adopted over the county's mitigation plan. While the individualistic atmosphere of hazard mitigation planning hinders the creation of an inclusive and comprehensive county-wide hazard mitigation planning environment, it does provide an opportunity for land use and hazard mitigation planning to more easily join forces as they are exercised on the same local level.

IMPLEMENTING STRUCTURAL MITIGATION MEASURES

The second recommendation for reducing vulnerability to flooding, especially to critical infrastructure in Galveston County is through the specific implementation of structural mitigation measures. Coastal disaster mitigation has traditionally applied structural protection to "armor or shield coastal communities and residents against the forces of nature."[53] While structural solutions can come with social, economic and ecological costs, structural mitigation strategies remain attractive solutions because they provide a clear level of protection for people and infrastructure that populate vulnerable areas.

The implementation of specific structural mitigation measures is an important level of protection that Clear Lake, Texas City, La Marque and City of Galveston should

[53] (Beatley 2009)

provide to the population and critical infrastructure that is most exposed to high flood risk. Specifically, structural mitigation should be focused on protecting the highly vulnerable and most exposed critical infrastructure. These measures should include ensuring structurally sound buildings and the implementation of structural protection where building retrofits are not enough to fully protect the infrastructure. While complete avoidance of vulnerable coastal areas is not feasible in Galveston County, the use of structural mitigation measures to protect the most vulnerable population and infrastructure is important. Ultimately, Clear Lake, Texas City, La Marque and the City of Galveston have the responsibility to protect their coastal population and infrastructure from flood risk; in this protection effort, these cities should implement a variety of mitigation measures to protect their coastal populations and infrastructure. The use of structural mitigation measures should be implemented for the population and infrastructure that resides in the most vulnerable locations and are most at risk to flooding.

RESILIENCY TARGETS AND BENCHMARKS

The last recommendation for Galveston County and its cities to reduce vulnerability to flooding is through the creation of community-specific benchmarks that are aimed at resiliency building. Through the development of resilience targets and accompanying metrics, cities are able to track the progress of their efforts which are aimed at building resilience to flood risk. This way, resilience building becomes an active goal of local communities. Examples of resilience targets could include:

1) Updating hazard mitigation plans

2) Hiring a resilience officer
3) Reaching a certain percentage of local businesses, especially utilities that have prepared hazard recovery plans[54]

The metrics that can be used to track the process of communities' reaching the resilience targets could include:

1) Percentage of homes and buildings in the community that are meeting minimum building standards[55]
2) Percentage of development and critical infrastructure within 100-year floodplain and hurricane storm surge zones
3) Percentage of businesses with hazard recovery plans
4) Extent of damages (public and private) from flooding events[56]

Through the implementation of these community-specific resilience benchmarks, communities will have the opportunity to reduce their vulnerability to flood risk and build coastal resilience in a more tangible manner. It is important that these resilience building efforts are recognized by local government officials, business owners, developers, and residents; the participation and cooperation across all local players is critical if communities in Galveston County will have a resilient future.

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[54] (Beatley 2009)
[55] (Beatley 2009)
[56] (Beatley 2009)

Research and Data Limitations

There are several data limitations that have impacted this research. The first is the use of somewhat outdated imperviousness data. The imperviousness data is from 2006, and due to rapid development that has occurred in Galveston County, I believe that the use of more current imperviousness data would show that there are even more block groups and parcels are exposed to a high vulnerability of flood risk in Galveston County than already accounted for in the current vulnerability index.

Additionally, there are some elements of critical infrastructure that were not included in the analysis. The categories of critical infrastructure that were used in the analysis were based on the land uses assigned to each parcel from the Galveston County Appraisal District. As referenced in this report, these categories include tax-exempt commercial (schools, churches, healthcare centers), water systems, utilities (gas, electric and telephone), railroads and pipelines. The critical infrastructure that was not specifically included in Galveston County Appraisal District's land use code assignments are hospitals and evacuation routes. This critical infrastructure provides important services to the community such that the damage to either category of infrastructure heavily impacts the community's resilience. The inclusion of hospitals and evacuation routes within the other parcels with critical infrastructure would provide an even more comprehensive assessment of the vulnerability to flood risk in Galveston County.

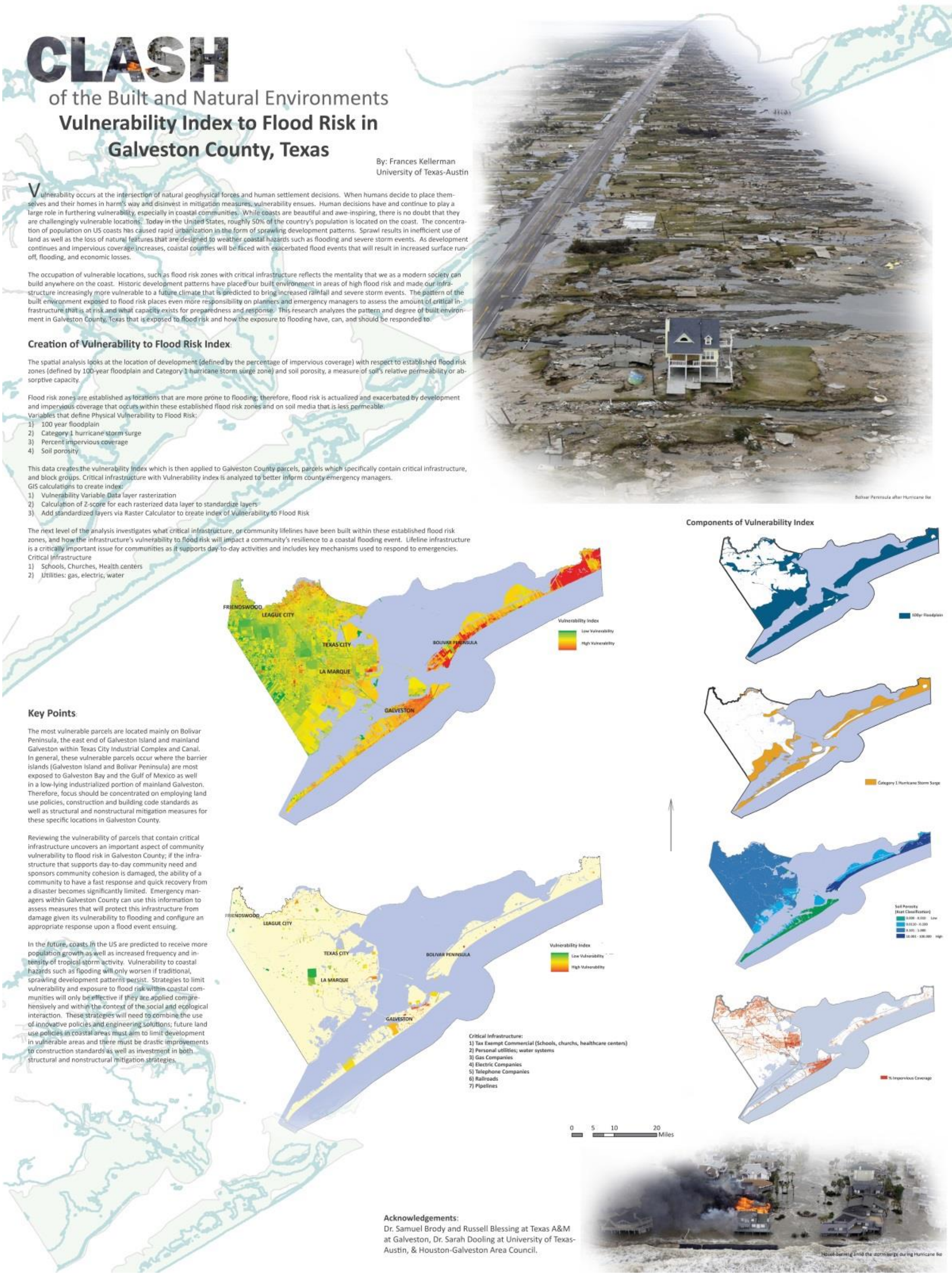
Next Steps and Future Research

The next steps in this research involve the integration of this vulnerability index within the Coastal Communities Planning Atlas. By integrating this physical vulnerability index for Galveston County on the block group level with the existing social vulnerability index already within the Planning Atlas, a comprehensive assessment of physical and social vulnerability can be conducted. The physical vulnerability index will also be immediately replicated for Brazoria County. As mentioned, the replicability of the physical vulnerability index allows for many more coastal counties within the Coastal Communities Planning Atlas to be analyzed on the block group level for their physical vulnerability to flood risk. Lastly, future steps should be taken to look into how jurisdictions like Bolivar Peninsula, that are not Home Rule cities, can gain authorization to engage in land use and hazard mitigation planning to protect their population and infrastructure along the coast from flooding.

CONCLUSION

The future is predicted to bring increasing population growth as well as increased frequency and intensity of tropical storm activity to coastal areas. Vulnerability to coastal hazards such as flooding will only worsen if we continue to develop in areas that are most vulnerable to coastal hazards. Galveston County has the chance to limit its vulnerability and exposure to flood risk through creative land use and hazard mitigation planning on the local level. Through a continual commitment to engaging in planning, Home Rule cities in Galveston County can better shape their physical landscape, guide development to the most appropriate locations, and ultimately limit vulnerability. Only through this sustained dedication on the local level to reducing exposure to flood risk will Galveston County become a resilient coastal community.

Appendix A


CLASH
of the Built and Natural Environments
Vulnerability Index to Flood Risk in Galveston County, Texas
By: Frances Kellerman
University of Texas-Austin
Vulnerability occurs at the intersection of natural geophysical forces and human settlement decisions. When humans decide to place themselves and their homes in harm's way and disinvest in mitigation measures, vulnerability ensues. Human decisions have and continue to play a large role in furthering vulnerability, especially in coastal communities. While coasts are beautiful and awe-inspiring, there is no doubt that they are challengingly vulnerable locations. Today in the United States, roughly 50% of the country's population is located on the coast. The concentration of population on US coasts has caused rapid urbanization in the form of sprawling development patterns. Sprawl results in inefficient use of land as well as the loss of natural features that are designed to weather coastal hazards such as flooding and severe storm events. As development continues and impervious coverage increases, coastal counties will be faced with exacerbated flood events that will result in increased surface run-off, flooding, and economic losses.
The occupation of vulnerable locations, such as flood risk zones with critical infrastructure reflects the mentality that we as a modern society can build anywhere on the coast. Historic development patterns have placed our built environment in areas of high flood risk and made our infrastructure increasingly more vulnerable to a future climate that is predicted to bring increased rainfall and severe storm events. The pattern of the built environment exposed to flood risk places even more responsibility on planners and emergency managers to assess the amount of critical infrastructure that is at risk and what capacity exists for preparedness and response. This research analyzes the pattern and degree of built environment in Galveston County, Texas that is exposed to flood risk and how the exposure to flooding have, can, and should be responded to.
Creation of Vulnerability to Flood Risk Index:
The spatial analysis looks at the location of development (defined by the percentage of impervious coverage) with respect to established flood risk zones (defined by 100-year floodplain and Category 1 hurricane storm surge zone) and soil porosity, a measure of soil's relative permeability or absorptive capacity.
Flood risk zones are established as locations that are more prone to flooding; therefore, flood risk is actualized and exacerbated by development and impervious coverage that occurs within these established flood risk zones and on soil media that is less permeable.
Variables that define Physical Vulnerability to Flood Risk:
1) 100 year floodplain
2) Category 1 hurricane storm surge
3) Percent impervious coverage
4) Soil porosity
This data creates the vulnerability index which is then applied to Galveston County parcels, parcels which specifically contain critical infrastructure, and block groups. Critical infrastructure with Vulnerability index is analyzed to better inform county emergency managers.
GIS calculations to create index:
1) Vulnerability Variable Data layer rasterization
2) Calculation of Z-score for each rasterized data layer to standardize layers
3) Add standardized layers via Raster Calculator to create index of Vulnerability to Flood Risk
The next level of the analysis investigates what critical infrastructure, or community lifelines have been built within these established flood risk zones, and how the infrastructure's vulnerability to flood risk will impact a community's resilience to a coastal flooding event. Lifeline infrastructure is a critically important issue for communities as it supports day-to-day activities and includes key mechanisms used to respond to emergencies.
Critical Infrastructure
1) Schools, Churches, Health centers
2) Utilities: gas, electric, water
Bolivar Peninsula after Hurricane Ike
Components of Vulnerability Index
100yr Floodplain
Category 1 Hurricane Storm Surge
Soil Porosity
(Ksat Classification)
Low
High
% Impervious Coverage
FRIENDSWOOD
LEAGUE CITY
TEXAS CITY
LA MARQUE
BOLIVAR PENINSULA
GALVESTON
Vulnerability Index
Low Vulnerability
High Vulnerability
Key Points:
The most vulnerable parcels are located mainly on Bolivar Peninsula, the east end of Galveston Island and mainland Galveston within Texas City Industrial Complex and Canal. In general, these vulnerable parcels occur where the barrier islands (Galveston Island and Bolivar Peninsula) are most exposed to Galveston Bay and the Gulf of Mexico as well in a low-lying industrialized portion of mainland Galveston. Therefore, focus should be concentrated on employing land use policies, construction and building code standards as well as structural and nonstructural mitigation measures for these specific locations in Galveston County.
Reviewing the vulnerability of parcels that contain critical infrastructure uncovers an important aspect of community vulnerability to flood risk in Galveston County; if the infrastructure that supports day-to-day community need and sponsors community cohesion is damaged, the ability of a community to have a fast response and quick recovery from a disaster becomes significantly limited. Emergency managers within Galveston County can use this information to assess measures that will protect this infrastructure from damage given its vulnerability to flooding and configure an appropriate response upon a flood event ensuing.
In the future, coasts in the US are predicted to receive more population growth as well as increased frequency and intensity of tropical storm activity. Vulnerability to coastal hazards such as flooding will only worsen if traditional, sprawling development patterns persist. Strategies to limit vulnerability and exposure to flood risk within coastal communities will only be effective if they are applied comprehensively and within the context of the social and ecological interaction. These strategies will need to combine the use of innovative policies and engineering solutions; future land use policies in coastal areas must aim to limit development in vulnerable areas and there must be drastic improvements to construction standards as well as investment in both structural and nonstructural mitigation strategies.
Critical Infrastructure:
1) Tax Exempt Commercial (Schools, churchs, healthcare centers)
2) Personal utilities; water systems
3) Gas Companies
4) Electric Companies
5) Telephone Companies
6) Railroads
7) Pipelines
0 5 10 20 Miles
Acknowledgements:
Dr. Samuel Brody and Russell Blessing at Texas A&M at Galveston, Dr. Sarah Dooling at University of Texas-Austin, & Houston-Galveston Area Council.

Appendix B

HAZARD MITIGATION PROFILE OF GALVESTON COUNTY

The primary policy and hazard planning response to flood risk in the county has been through structural mitigation measures. In general, the response to flood mitigation has been focused on structural interventions including the use of retention ponds, levees, and hardened channels; nonstructural techniques are employed less frequently throughout Galveston County.[57] The majority of these hazard mitigation planning and coordination efforts occur within the Home Rule cities within Galveston County. To glean more information about the status of hazard mitigation planning in Galveston County, interviews were conducted with a member of Galveston County's Office of Emergency Management as well as a member from Houston-Galveston Area Council (H-GAC), the regional Council of Governments as well as the coordinating arm for regional hazard mitigation planning. These interviews were aimed at gaining an understanding of the capacity or incapacity of emergency management teams to mitigate flood risk and be prepared and responsive to the built environment that is vulnerable to flooding. During the interviews, the interviewees were asked questions that refer specifically to hazard mitigation planning and response capacity. The four main questions that were asked include:

1) How vulnerable is the critical infrastructure given your organization's current capacity to respond and mitigate harm?

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[57] (Brody, Highfield and Kang, Rising Waters: The Causes and Consequences of Flooding in the United States 2011)

2) In the least and most severe flooding events, what resources can be mobilized to address the vulnerability?

3) What resources can complement existing capacity?

4) What resources do your organization not have now that are needed to more effectively prepare and respond to the least and most severe flooding risk?

H-GAC: Regional Hazard Mitigation Planning

In 2011, H-GAC was called to update the Regional Hazard Mitigation Plan based upon the 5-year update requirement from Texas Department of Emergency Management and FEMA. H-GAC worked in partnership with county emergency coordinators, which generally coordinate for the cities within their jurisdictions and distribute information. The 2011 Hazard Mitigation Plan Update covers seven counties: Austin, Brazoria, Chambers, Liberty, Montgomery, Walker and Waller. As shown, Galveston County was not included in the 2011 Plan Update. H-GAC coordinates regional hazard mitigation planning efforts directly with each of the 13 county's emergency management coordinators. The updated plan includes an analysis of recent repetitive-loss data associated with flooding, considerable storm surge impacts, expansion of wildfire vulnerability assessment, inclusion of 2010 census data, updated jurisdictional capability assessments, and the addition of 300 new mitigation projects.

The role that the county emergency managers play as the middle man between H-GAC and the region's 78 cities is helpful; however, not all cities want their respective counties to coordinate their hazard mitigation planning efforts. The process for updating H-GAC's regional hazard mitigation plan includes a call to all county emergency management coordinators requesting participation as well as a list of county and city specific mitigation actions. Thus, the participation of county office of emergency management and city emergency manager coordinators is voluntary. An advantage for counties to participate in the regional hazard mitigation plan is mitigation funding from H-GAC; however, participation hinges on a cash match put up by each jurisdiction. For some counties, the cash match is the deterrent for not participating in the regional hazard mitigation plans; these counties, especially the smaller, rural counties simply do not have enough money to meet the cash match for participation in the regional hazard mitigation plan. Other counties, notably Galveston County have more experience in coordinating hazard mitigation planning on their own and choose to continue planning hazard mitigation in this manner.

An identified challenge for H-GAC in the process of updating the regional hazard mitigation plan is the spotty participation from the region's jurisdictions. Some of the smaller jurisdictions within the region have mayors and other elected officials who have other full time jobs; it is a challenge to get these elected officials to make an effort to participate in the regional hazard mitigation process because it is not a top priority for them and their jurisdiction. In addition, the autonomy of Home Rule cities with respect to county governments results in a silo approach to hazard mitigation efforts within each county. Ultimately, this patchwork of local hazard mitigation planning makes the creation of comprehensive county- and region-wide mitigation plans much more difficult.

Galveston County: Hazard Mitigation Planning

In Galveston County, county-wide hazard mitigation planning and coordination that is promoted and endorsed by Galveston County's office of emergency management (OEM) is a point of contention. The clash of power between Home Rule cities and the county is very present, and dictates an independent nature of hazard mitigation planning in the county. Each home rule city has an emergency manager who coordinates the city's own hazard mitigation plan. Often, the city emergency manager establishes a city-wide hazard mitigation plan that is adopted by the city over the county's mitigation plan. In other words, Home Rule cities in Galveston County establish a mitigation planning organization that is independent of the county's mitigation planning.

There are some instances of working relationships between the Home Rule cities and the county office of emergency management, such as between City of Galveston and Galveston County OEM. Other cities, like Texas City, another Home Rule city choose to keep their mitigation planning entirely separate from the county. If a disaster were to occur in Galveston County, there is a strong confidence that all emergency managers through the county would bind together and work through the disaster together; however, on a day to day basis, the silo effect for hazard mitigation planning occurring independently on the local level is practiced.

Another issue that has been identified is the lack of documented hazard mitigation planning processes for Home Rule cities in Galveston County. The majority of the emergency managers of the Home Rule cities have an innate understanding of hazards within their jurisdictions and have long since adopted appropriate methods for managing the city's resources in the face of a disaster. My interviewee indicated that "while this does not create a very sophisticated planning environment, we have people [emergency managers of the county's Home Rule cities] who know what they are doing and know how to adapt and overcome [disasters], even if it's not pretty." While there is strong institutional knowledge found within the independent hazard mitigation planning efforts of the cities within the county, there is a great lack of written planning processes. This method of hazard mitigation planning works for the time being; however, the problem becomes more complicated when these established emergency manager coordinators are no longer present and they take with them all of the institutionalized knowledge of local hazards.

There is a push for more coordination among emergency managers in the county will help to ensure that the emergency response is more robust. David Popoff who heads Galveston County Office of Emergency Management has been working hard to promote more of this cohesion. While Popoff is well-respected throughout the county, the promotion of county-wide hazard mitigation planning and coordination is no easy task. My interviewee related the process of promoting county-wide mitigation planning to making scrambled eggs; the process requires "some eggshells to be cracked." While progress is slow, my interviewee feels positive that this county-wide coordination will happen in the future.

Galveston County is believed to be a well-resourced county, given a robust alert systems network and mobile command post. Despite the confidence of a well-resourced county, there is no denying that Galveston County is greatly vulnerable to flooding. The takeaways from the interviews with members from H-GAC and Galveston County OEM show that hazard mitigation planning, the planning that addresses this vulnerability, occurs in a spotty manner. Efforts to make hazard mitigation planning more comprehensive goes against the grain of the current mentality towards planning in Texas; however, the future looks positive for more comprehensive planning and coordination in the hazard mitigation realm to occur. Comprehensive planning efforts appear to be Galveston County's opportunity to best address the given vulnerability and limit future vulnerability to flooding. Inclusive hazard mitigation planning throughout the county may be Galveston's best chance to increase its resiliency.

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